

HSR

High Speed Research - Configuration Aerodynamics

Langley Research Center



Viscous Design of TCA Configuration

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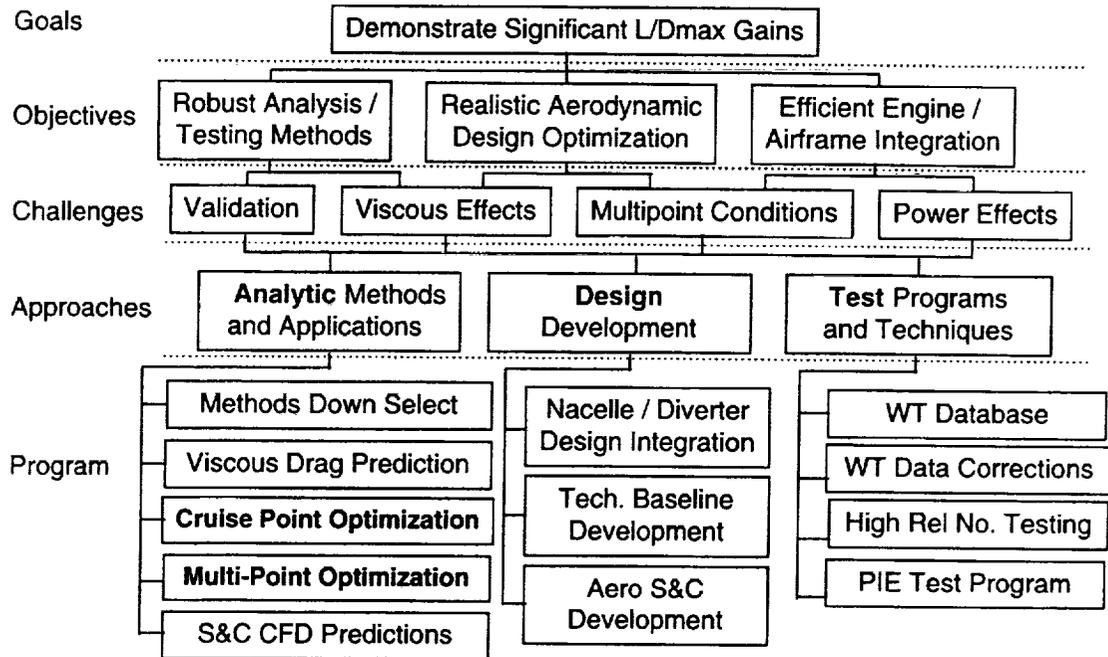
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Viscous Design of TCA Configuration

The goal in this effort is to redesign the baseline TCA configuration for improved performance at both supersonic and transonic cruise. Viscous analyses are conducted with OVERFLOW, a Navier-Stokes code for overset grids, using PEGSUS to compute the interpolations between overset grids. Viscous designs are conducted with OVERDISC, a script which couples OVERFLOW with the Constrained Direct Iterative Surface Curvature (CDISC) inverse design method.

Configuration Aerodynamics Technology Development

Session 3: Aerodynamic Design Optimization Capability



Configuration Aerodynamics Technology Development

This work was performed under the Configuration Aerodynamics element of the High Speed Research program. The specific milestones addressed are Cruise Point Optimization and Multi-Point Optimization.

Outline

- Automated Griding For TCA Designs
- OVERDISC Inverse Design Procedure
- Dual-Point Redesign of BCAG TCA Optimized Configuration
- Natural Flow Wing Design of TCA

Outline

The successful execution of any computational fluid dynamics (CFD) based aerodynamic design method for complex configurations requires an efficient method for regenerating the computational grids to account for modifications to the configuration shape. The first section of this presentation deals with the automated regridding procedure used to generate overset grids for the fuselage/wing/diverter/nacelle configurations analysed in this effort. The second section outlines the procedures utilized to conduct OVERDISC inverse designs. The third section briefly covers the work conducted by Dick Campbell, in which a dual-point design at Mach 2.4 and 0.9 was attempted using OVERDISC; the initial configuration from which this design effort was started is an early version of the optimized shape for the TCA configuration developed by the Boeing Commercial Airplane Group (BCAG), which eventually evolved into the NCV design. The final section presents results from application of the Natural Flow Wing design philosophy to the TCA configuration.

Automated Gridding of TCA Designs

- Modifications to TCA Baseline Overset Grids Supplied by BCAG
 - Wall spacings for transonic cruise
 - Topology modifications for regriding and PEGSUS41–46
- Wing/Body script to generate volume grids from fuselage and wing surface grids
- Rerig Nacelles Satisfying Constraints
 - Fixed inboard and outboard nacelle hard points on wing t.e.
 - Clearance between nacelle lip and wing lower surface
 - Avoid nacelle protrusion through rear spar
- Regrid nacelle component grids
- Run PEGSUS

Automated Gridding of TCA Designs

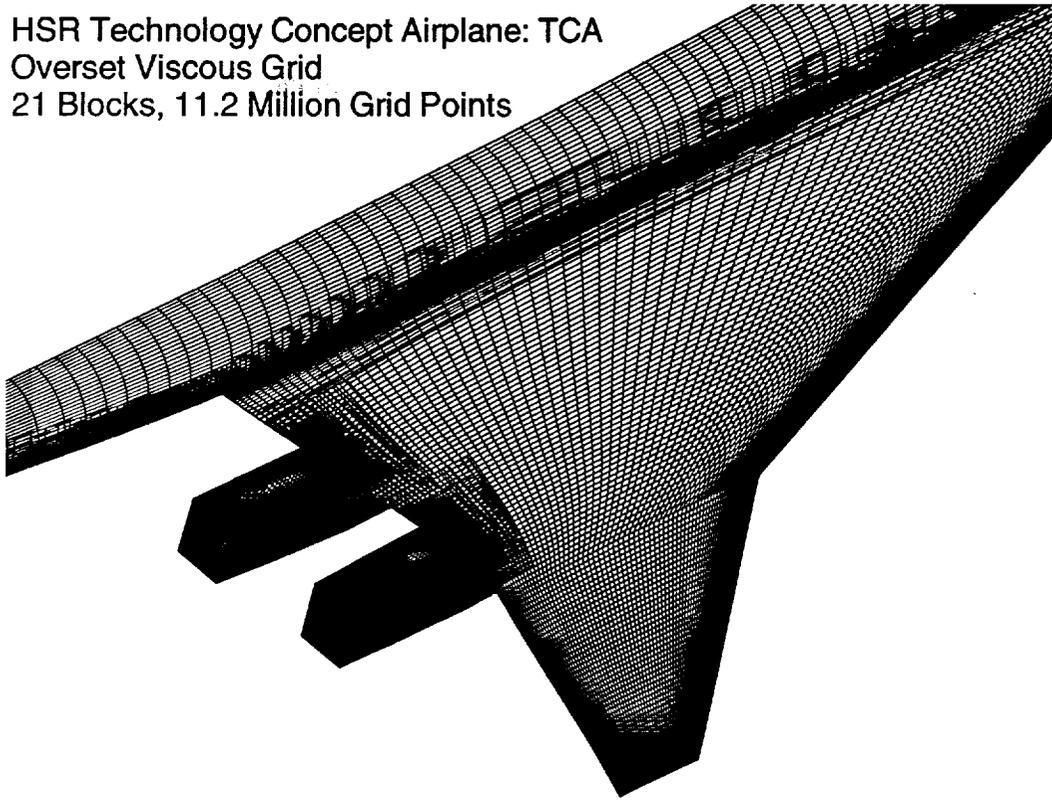
The initial overset grids utilized in this effort were developed by Steve Chaney and Steve Ogg at BCAG. While the grids were initially sized for the Mach 2.4 cruise condition, they were modified for the Mach 0.90 cruise condition by decreasing the wall-normal spacing to a third of its original value, thereby maintaining a y^+ value of one. A slight change to the topology was also made to the nacelles. This change permits the use of PEGSUS version 41–46, which is roughly seven times faster than version 41–36, which was required for the successful interpolation of the initial set of overset grids.

The intent in the regriding procedure is to automatically generate the complete set of overset volume grids for the fuselage/wing/diverter/nacelle configuration, starting from fuselage and wing surface grids, for any fuselage/wing configuration shape on the TCA platform. At this point in the effort, the diverters and nacelles are not being redesigned.

The first step in the regriding procedure is to generate the fuselage/wing volume grids using a modified version of the Wing/Body script developed in the Advanced Subsonic Transport (AST) program. The second step is to rerig the nacelles on the configuration. Constraints on the nacelle positioning are utilized to ensure clearance between the nacelle upper surface ejector port and the wing upper surface (the nacelles protrude through the upper surface of the wing near the wing trailing edge), to provide sufficient clearance between the wing lower surface and the nacelle inlet lip to avoid boundary layer ingestion, and to prevent the nacelle surface from cutting into the rear spar of the wing. Once the nacelles are positioned correctly, the overset component grids are restretched and reprojected onto the appropriate surfaces to ensure consistency between the grid blocks. Further details of the nacelle installation procedure are presented on the following 3 pages.

The last step in the procedure is to run PEGSUS to compute the interpolations between the new system of overset grids. The entire regriding procedure, from generation of the fuselage/wing grids to completion of PEGSUS is implemented with a unix script. Through numerous designs, this fully automated procedure has been found to be quite robust, typically generating on the order of 10 orphan points for new configurations.

HSR Technology Concept Airplane: TCA
Overset Viscous Grid
21 Blocks, 11.2 Million Grid Points



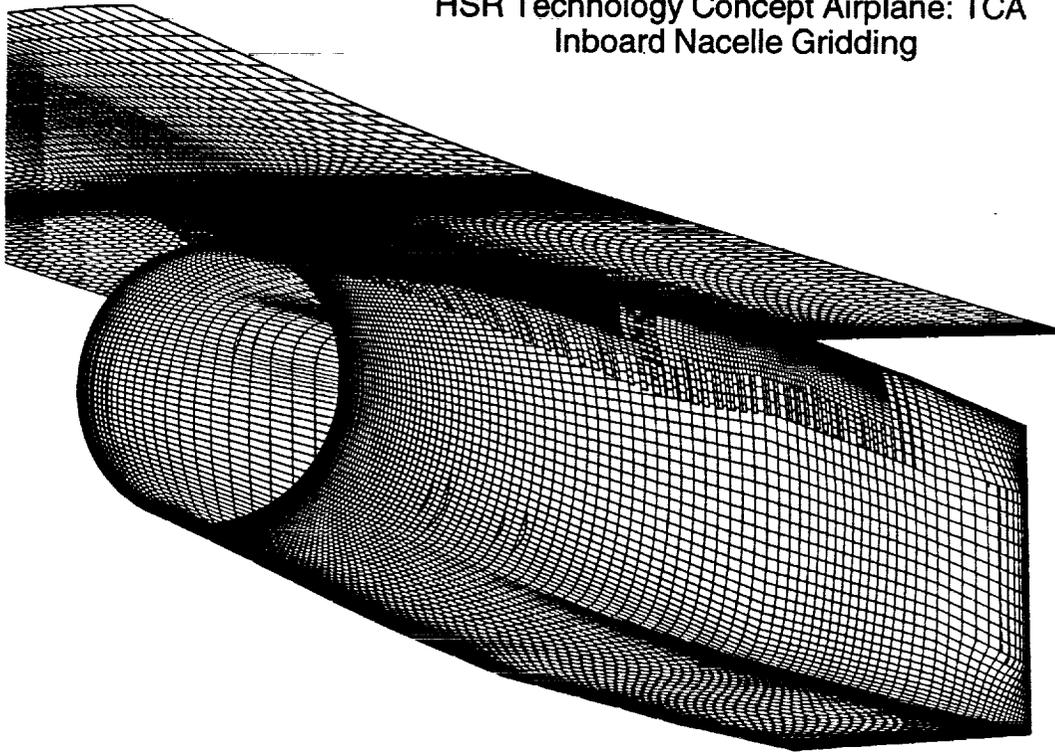
TCA Overset Viscous Grid

The fuselage/wing/diverter/nacelle system of overset grids utilized throughout this work is comprised of 21 blocks containing a total of 11.2 million grid points. Several of the surface grids for the configuration are shown in the figure, where the view is from above, outboard, and behind the wing.

The advantage to using overset rather than abutting structured grids is that each component of the configuration can be gridded independently. In this case, independent grids are generated for the wing and fuselage, and a third grid, referred to as the collar grid, is automatically generated to handle the intersection of the wing with the fuselage. To grid the diverters and nacelles, a total of 8 grids are used for each nacelle/diverter combination. The internal and external nacelle surfaces are each handled with one grid, while each side of the diverter is treated with a forward and aft grid which differ somewhat in topology. Since the nacelles protrude through the upper surface of the wing, an additional fairing grid is used to handle the intersection of the wing upper surface with the nacelle. The eighth grid is a box-like grid which encloses most of the nacelle, but has one surface lying on the wing lower surface; the box-like grid runs well downstream of the end of the nacelle.

While overset methods allow for relatively simple gridding procedures as compared to the procedures for constructing abutting grids, it presents additional difficulties in that invalid portions of a grid must be cut out (e.g. that portion of the nacelle external volume grid which runs through the wing and diverter), and appropriate interpolations between grids must be computed. Construction of the PEGSUS input file to perform these tasks can be quite formidable. Moreover, special care is required in design problems to keep the hole cutting specifications flexible enough to handle significantly different configurations.

HSR Technology Concept Airplane: TCA Inboard Nacelle Gridding



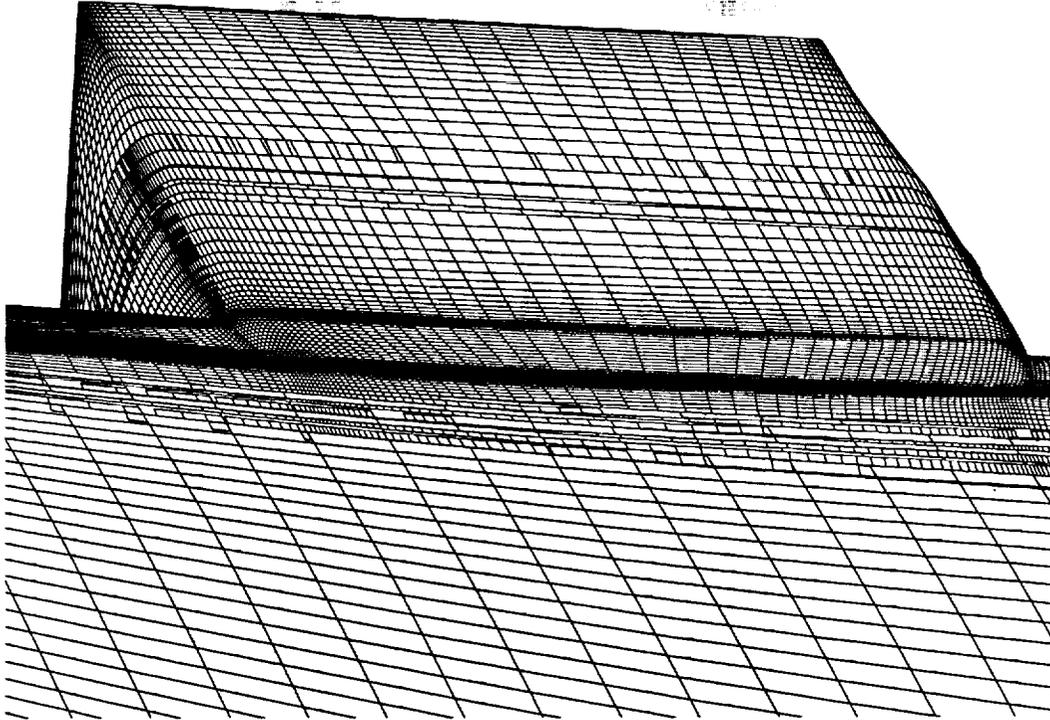
TCA Inboard Nacelle Gridding

Surface grids from several components of the inboard nacelle are shown in the figure, where the view is from inboard and below the inboard nacelle. The upper most grid is the surface of the box-like grid which lies on the lower surface of the wing, which has only been represented up to the trailing edge of the wing. The forward inboard diverter grid contains three viscous surfaces, lying on the lower wing surface, the diverter, and the nacelle. The aft diverter grid contains two viscous surfaces; separate surfaces for the diverter and nacelle are not required near the trailing edge since the angle between the two surfaces is quite shallow.

In rigging the nacelle, the ejector port clearance with the wing upper surface is maintained in approximate fashion, namely, fixed points on the aft inboard and outboard diverter grids are required to lie on the wing trailing edge at a specific span station. After a configuration change, the hard point on the inboard diverter is translated to lie on the wing trailing edge. The nacelle is then rotated to position the outboard hard point onto the wing trailing edge, adding both yaw and roll to the nacelle orientation. The lip of the nacelle is then positioned to meet a distance constraint between the lip and the lower surface of the wing, which changes the inclination of the nacelle. A check is then made to ensure that the nacelle does not cut into the lower spar of the wing; if it does, the lip is rotated down until the constraint is met. With the nacelle properly positioned, all of the nacelle component volume grids are subjected to the same series of translations and rotations.

At this point, all that remains to finish the gridding is to ensure that the surfaces of the diverter, upper surface fairing, and box-like grids lie on the appropriate overlapping surfaces of the wing, diverter, and nacelle. This is done through a series of surface projections with appropriate stretching of the volume grids. Treatments for the diverter and box-like component grids are fairly straight forward. Treatment of the upper surface fairing is not.

HSR Technology Concept Airplane: TCA Nacelle Fairing Grid



TCA Nacelle Fairing Grid

The nacelle fairing surface grid is shown in the figure, where the view is from on top of the wing slightly upstream of the fairing. The upstream portion of the fairing lies on the wing upper surface until it reaches the horizontal intersection line of the wing with the nacelle (the horizontal region of compressed grid spacing). At that point, the sides of the fairing surface grid continue on the wing upper surface, while the center of the grid lies on the nacelle. Downstream of the trailing edge, the sides of the fairing surface grid are treated like a wake, while the center of the surface grid remains on the nacelle. To regrid the fairing, three intersection lines between the wing and nacelle surfaces must be computed, and the surface grid must be restretched and reprojected appropriately, with particular care required at the corners of the intersection lines. Details are left to the readers imagination.

OVERDISC Inverse Design Procedure

Script to loop through the design process using:

- CDISCRUN: runs CDISC with a pre-processor to extract design information and a post-processor to output modified surface grids
- Grid Manipulation Script: rerig nacelles to meet design constraints and perturb volume grids to maintain grid continuity between overlapping blocks
- PEGSUS: recompute interpolations between overset grids
- MIXSUR: recompute force and moment interpolation stencils
- OVERFLOW: Update solution for modified configuration

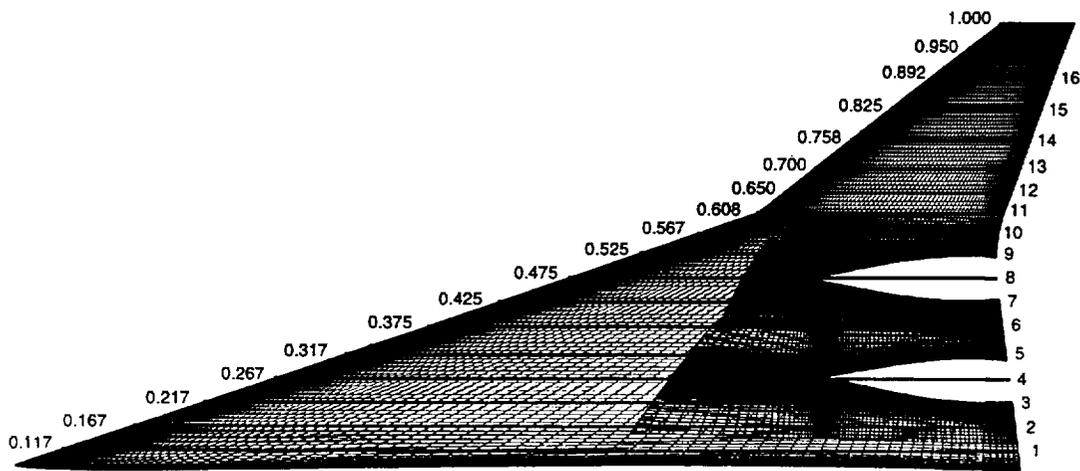
OVERDISC Inverse Design Procedure

OVERDISC is a unix script which couples the CDISC inverse design method with the OVERFLOW analysis code. The coupling is implemented by extracting information from the OVERFLOW solution and grid files for use in CDISC, regenerating the overset volume grids to conform to the configuration modifications output from CDISC, and running PEGSUS to compute the interpolations between the new system of overset grids. In order to maintain a history of the configuration forces and moments through the course of the design, an additional step is required, namely, running MIXSUR to compute the interpolation stencils for the overset surface grids.

Typical OVERDISC designs at the Mach 2.4 cruise condition were run for 10 design cycles with 40 multigrid iterations per design cycle and 150 multigrid iterations to obtain convergence of the final design. The computation time required for a complete design was on the order of 24 hours on a C90, which is nearly equivalent to the time it takes to obtain a converged solution of the initial configuration. The time spent on running CDISC, the automated regridding script, PEGSUS, and MIXSUR was roughly 1 hour per design cycle, or about the same time required to run OVERFLOW for 40 multigrid iterations. The time spent on the design portion of the script can be reduced by skipping the PEGSUS run, for all but the final design, and using the initial interpolation file in analyzing the intermediate designs. This procedure saved about 2/3 of an hour per design cycle and proved to be quite robust; it was used extensively. Nevertheless, runs of the OVERDISC script in the multitask mode averaged less than 2 CPU's on the C90, whereas OVERFLOW runs average about 6 CPU's;

While the automated gridding script and PEGSUS runs proved to be quite robust, computation of the surface grid interpolation stencils in MIXSUR were not; particularly troublesome was the lower surface of the wing, which contains 12 overlapping surface grids. In fact, the input file to MIXSUR had to be modified for most of the designs before the final forces and moments could be computed. This difficulty suggests that in developing automated regridding scripts for designs, surface projections should always be implemented with parametric projections.

TCA Design Stations Wing Lower Surface



TCA Design Stations

A crucial element in utilizing OVERDISC is creation of the CDISC "target" file, in which design stations, as well as flow and geometry constraints at those stations, are specified. CDISC is a knowledge-based approach to design for which the typical mode of operation is to use flow constraints to modify the current analysis pressure distributions at the design stations to develop target pressure distributions. Differences between the analysis and target pressure distributions are then related to surface curvature changes along the design stations. Geometry constraints are directly imposed on the new surface shapes. Multiple passes are made through both the flow and geometry constraints in an attempt to satisfy all the requirements. Grid lines lying between design stations are modified by linear interpolation of the surface increments computed at the encompassing design stations.

Flow and geometry constraints are grouped into three general categories. Global constraints influence multiple design stations (e.g. spanload or twist distribution). Section constraints affect both surfaces on, say, an airfoil (e.g. section lift coefficient or minimum thickness at a spar). Surface constraints are applied to a single aerodynamic surface (e.g. shock strength or surface curvature restrictions).

The design stations utilized in a typical OVERDISC design of the TCA configuration, superimposed on the lower surface of the wing, are illustrated in the figure. Note that CDISC design stations must lie along grid lines; in this case they lie along grid lines of the wing. The coupling with OVERFLOW is such that a design station can run through a blanked out section of the grid; the preprocessor PREDISC is used to interpolate information from the appropriate overlapping grid to grid points along the specified grid line. In instances where the design station runs through a solid surface (e.g. stations 4 and 8 which run through the diverters), options are available to turn off the flow constraints in the invalid section of the station, but geometry constraints are still applied.

As suggested by the figure, in this work, OVERDISC was only used to design the wing. In order to prevent discontinuities in the grid, the 1st design station was always held fixed.

TCA Design Constraints Imposed on the Wing

- Forward and Rear Spar Thickness Distributions
- 2.4% Maximum Thickness/Chord Ratio as a Minimum
- Leading Edge Radius Constraint
- Volume Constraint Between Inboard Spars

TCA Design Constraints Imposed on the Wing

Constraints on redesigns of the wing for the TCA configuration are as follows:

- Minimum wing thickness distribution along the forward and rear spars
- 2.4% maximum thickness/chord ratio, as a minimum
- Minimum leading edge radius: the spanwise distribution is only specified inboard of the wing leading edge break
- Minimum volume between the forward and rear spars, for the section of the wing inboard of the wing leading edge break

All of the constraints were satisfied in all of the OVERDISC redesigns of the wing.

OVERDISC Dual-Point Design of TCA

- Weighted Average of Geometries (WAG)
 - Use CDISC to generate independent single point designs at multiple design points
 - Blend the geometries at each surface grid point based on a weighted average to minimize an objective function

- Two-point design procedure:
 - Design for reduced drag at $M=0.95$ and 2.4
 - Analyze point designs at opposing conditions
 - Compute geometry weighting factor based on objective function and constraints
 - Blend point design geometries and re-analyze at the two design points
 - Continue last two steps until minimum of objective function is determined

OVERDISC Dual-Point Design of TCA

The attempt in this effort was to take one of the TCA configurations generated with an aerodynamic optimization code and redesign the wing for improved performance at both supersonic and transonic cruise. The design method used is the Weighted Average of Geometries (WAG) method embodied in CDISC. In this method, CDISC is used to generate independent single point designs at multiple design points. The geometries from the various designs are then blended at each surface grid point using a weighted average, in an attempt to minimize an objective function.

Status of TCA Dual-Point Design

- Start from BCAG Optimized Configuration (Early Design), with modified diverter/nacelle topology

- Initial Single Point Designs with OVERDISC
 - M=2.4
 - << design objective: reduce shock strength
 - << 0.7 count drag reduction
 - M = 0.95
 - << design objective: recamber for larger L/D
 - << 11.0 count drag reduction

- Evaluate Single Point Designs at Opposing Conditions
 - M = 0.95 design never converged at M = 2.4

- Status: Switch Effort to Look at Flap Scheduling and Design

Status of Dual-Point Design

The starting point for the dual-point design of the TCA configuration was from an optimized configuration developed by BCAG which showed a 5.6 count drag reduction over the TCA baseline configuration; the optimized configuration is actually a precursor to the NCV design developed by BCAG.

The first step in the WAG method was to redesign the configuration at Mach 2.4. The attempt in this design was merely to reduce the strength of the compression seen on the wing lower surface resulting from the shocks emanating from the diverters and nacelles. The design provided an additional 0.7 count drag reduction over that of the optimized configuration; further details of the design are provided on the following two pages.

The second step was to redesign the configuration at Mach 0.95. The attempt in the design was to recamber the wing in order to improve the L/D ratio. The design led to an 11.0 count drag reduction over that of the optimized configuration.

The third step was to evaluate the single point designs at the opposing conditions. While the evaluation was not a problem for the Mach 2.4 design at Mach 0.95, the solution for the Mach 0.95 design at Mach 2.4 never did converge. However, it was apparent that the Mach 0.95 design would show large deteriorations in performance at the Mach 2.4 condition. Since 1 count of drag reduction at supersonic conditions is weighted equal to 4 counts of drag reduction at the transonic condition, it was evident that the WAG procedure would lead to use of the Mach 2.4 design solely, rather than blending the two designs. Hence, the dual-point design effort was terminated at this point.

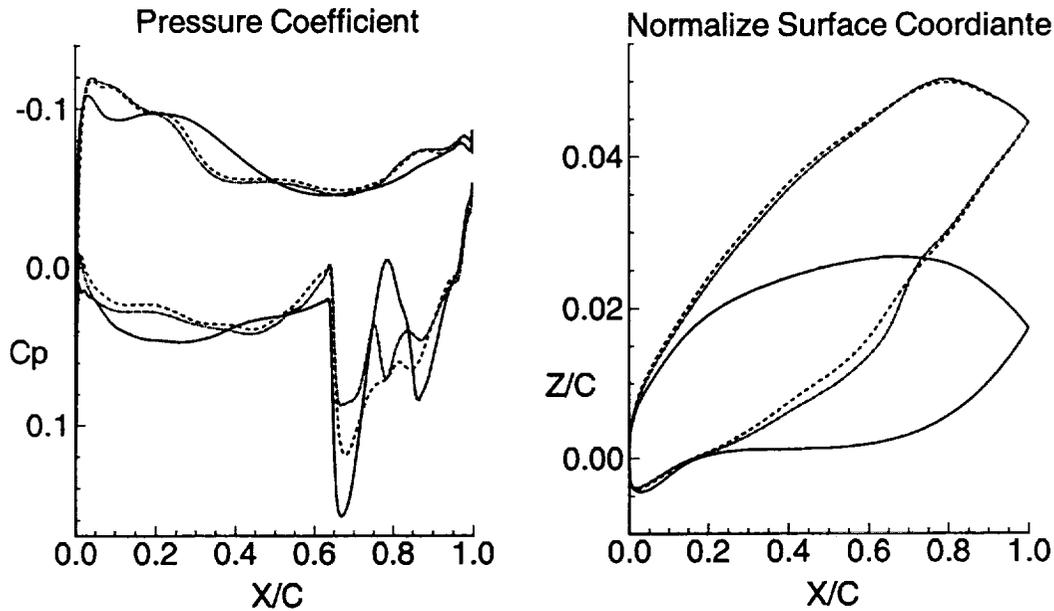
It is apparent from this effort that starting a multi-point design from a single point supersonic cruise design, without considering flap deflections at the transonic conditions, is impractical for the TCA configuration.

TCA Designs

M = 2.40
Re = 4.0×10^6

———— baseline $\alpha = 3.00^\circ$
- - - - BCAG $\alpha = 3.98^\circ$
- · - · - BCAG + OVERDISC $\alpha = 3.98^\circ$

$\eta = 0.416$



TCA Designs: Surface Pressure Coefficient and Normalized Coordinate at 0.416

The attempt in the Mach 2.4 redesign of the optimized configuration was to reduce the compression on the wing lower surface resulting from the shocks emanating off the nacelles and diverters. In CDISC, this was implemented by "constraining" the pressure coefficient in the vicinity of the shock to remain above some specified level, with varying levels used at the different design stations.

The figure shows the surface pressure coefficient and normalized coordinate at the 41.6% span station, which lies just inboard of the outboard nacelle, for the TCA baseline, BCAG optimized, and OVERDISC redesigned configurations. The constraint applied within CDISC was to limit the pressure coefficient at the design station to be below 0.08 in the vicinity of the shock. This leads to the addition of a convex increment in the surface coordinate in the vicinity of the shock. In order to close the airfoil at the leading and trailing edges, regions forward and aft of the shock are modified with concave increments to the surface curvature. Geometry constraints on the spar thickness and maximum thickness are then applied, leading to the changes seen in the upper surface shape.

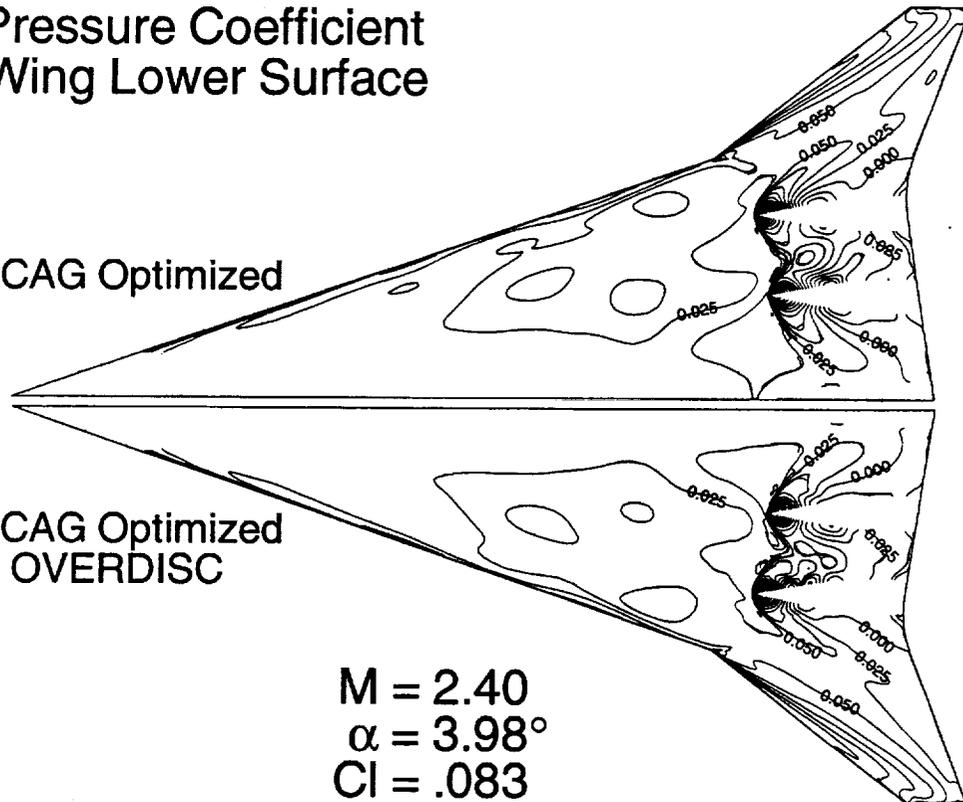
The results indicate that the strength of the compression has been significantly reduced with the OVERDISC design, but that the pressure recovery aft of the shock is somewhat less favorable than that for the optimized configuration.

Pressure Coefficient Wing Lower Surface

BCAG Optimized

BCAG Optimized
+ OVERDISC

$M = 2.40$
 $\alpha = 3.98^\circ$
 $C_l = .083$



Lower Surface Pressure Coefficient on the Optimized and OVERDISC designs at Mach 2.4

Pressure Coefficient distributions on the lower surface of the BCAG optimized and OVERDISC redesigned configurations at Mach 2.4 are shown in the figure. It is evident that the shock footprints on the lower surface have been reduced with the OVERDISC redesign.

Natural Flow Wing Design Procedure

- Apply NFW Concept and Conduct Euler Analyses of Wing/Body Configuration at $M=2.4$ to Refine Thickness, Camber, Etc.
 - Blunt leading edge outboard of leading edge break
 - Landing gear incorporated into fuselage
- OVERFLOW Analyses of NFW W/B/N/D Configurations at Supersonic and Transonic Cruise
- OVERDISC Inverse Design The Best Configuration

Natural Flow Wing Design Procedure

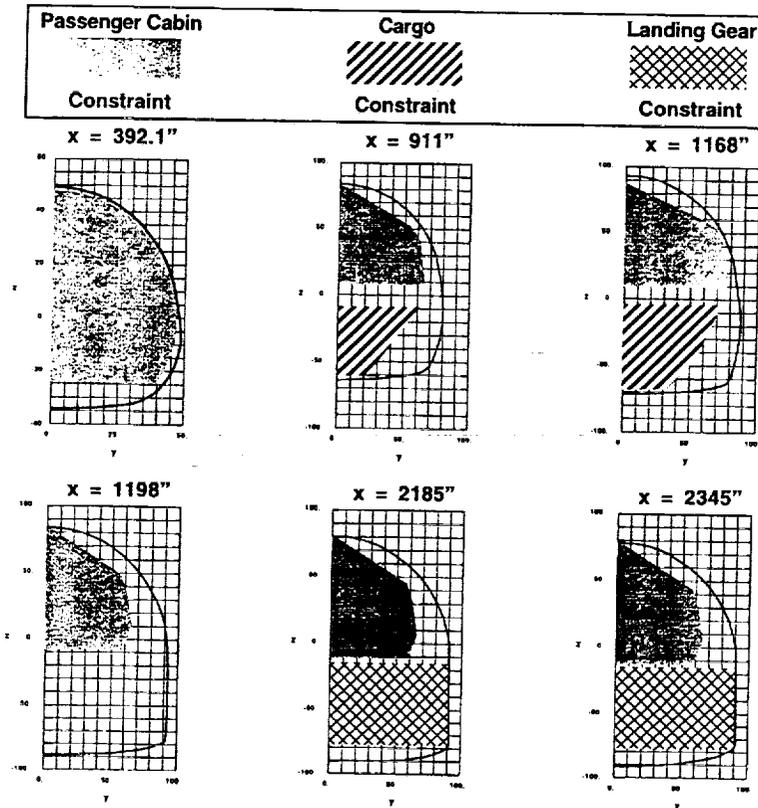
The Natural Flow Wing (NFW) Design philosophy was developed by Rick Woods and Steve Bauer to provide multipoint performance improvements for fighter aircraft over a range of transonic and supersonic flight conditions. Details of the design philosophy are reported in the 1996 HSR workshop proceedings under the title "Application of the Natural Flow Wing Design Philosophy to the HSR Arrow Wing Configuration".

Initial application of the NFW design philosophy to the TCA configuration was implemented through Euler analyses of the fuselage/wing configuration at Mach 2.4. Parametric studies were utilized to refine thickness, camber and twist distributions. There are two aspects of the resulting NFW designs which differ significantly from both the TCA baseline and the optimized configurations developed by other participants in the HSR program. First, the entire landing gear constraint is incorporated into the fuselage, rather than incorporating it into both the fuselage and wing; details of the fuselage shape are illustrated on the following page. Second, as a means for improving transonic performance, the airfoil sections outboard of the wing leading edge break are blunt rather than sharp.

The more promising NFW configurations developed in the initial study were analyzed at both the Mach 2.4 and 0.90 cruise conditions using OVERFLOW. Grids for the fuselage/wing/diverter/nacelle configurations were generated using the automatic regriding procedure discussed in the first section of this presentation.

The most promising NFW configuration, referred to as NFW701, provided drag reductions of 1.4 and 10.2 counts at the supersonic and transonic cruise conditions, respectively, over that of the TCA baseline. OVERDISC was then used to redesign the NFW701 configuration at Mach 2.4.

NASA LaRC TCA-NFW FUSELAGE AND CONSTRAINTS



TCA-NFW Fuselage and Constraints

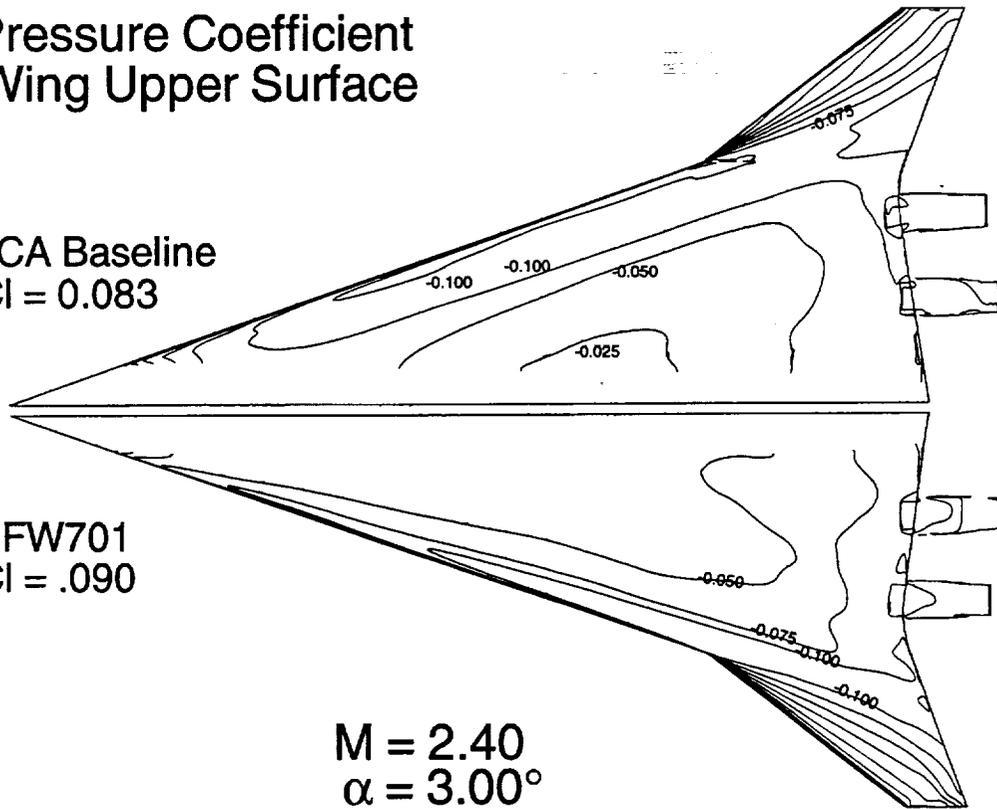
The figure shows the NFW fuselage outer mold line and TCA constraints at six cross-sections; note that the scales at station 392.1 differ from the scales used at the other five stations. The most significant aspect of the NFW fuselage design is that the entire landing gear constraint is incorporated into the fuselage. Due to the spanwise extent of the landing gear, the passenger cabin constraint applied at stations 2185 and 2345 is the same constraint applied at station 1198, rather than applying the specified TCA constraint which is much less severe. Application of the larger passenger cabin constraint would allow for an additional seat or two per row over the mid section of the fuselage.

Pressure Coefficient Wing Upper Surface

TCA Baseline
 $C_l = 0.083$

NFW701
 $C_l = .090$

$M = 2.40$
 $\alpha = 3.00^\circ$



Upper Surface Pressure Coefficient on the TCA Baseline and NFW701 at Mach 2.40

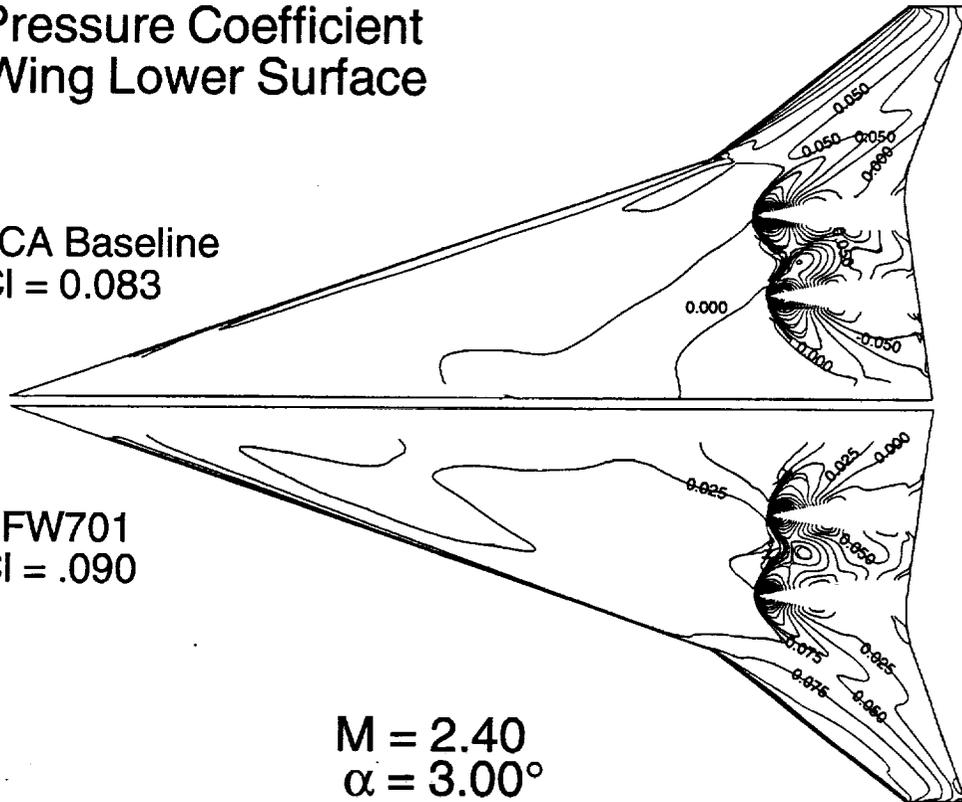
Pressure coefficient distributions on the upper surface of the wings for the TCA baseline and NFW701 configurations at Mach 2.4 are shown in the figure. Note that the configurations are run at the same angle of attack, but the NFW701 lift coefficient is 0.90 rather than 0.83. It is evident that the NFW701 design embodies significantly less leading edge suction along the entire span. The effect of using blunt airfoil sections outboard of the leading edge break in the NFW701 design is indicated by the higher pressures near the leading edge.

Pressure Coefficient Wing Lower Surface

TCA Baseline
 $C_l = 0.083$

NFW701
 $C_l = .090$

$M = 2.40$
 $\alpha = 3.00^\circ$



Lower Surface Pressure Coefficient on the TCA Baseline and NFW701 at Mach 2.40

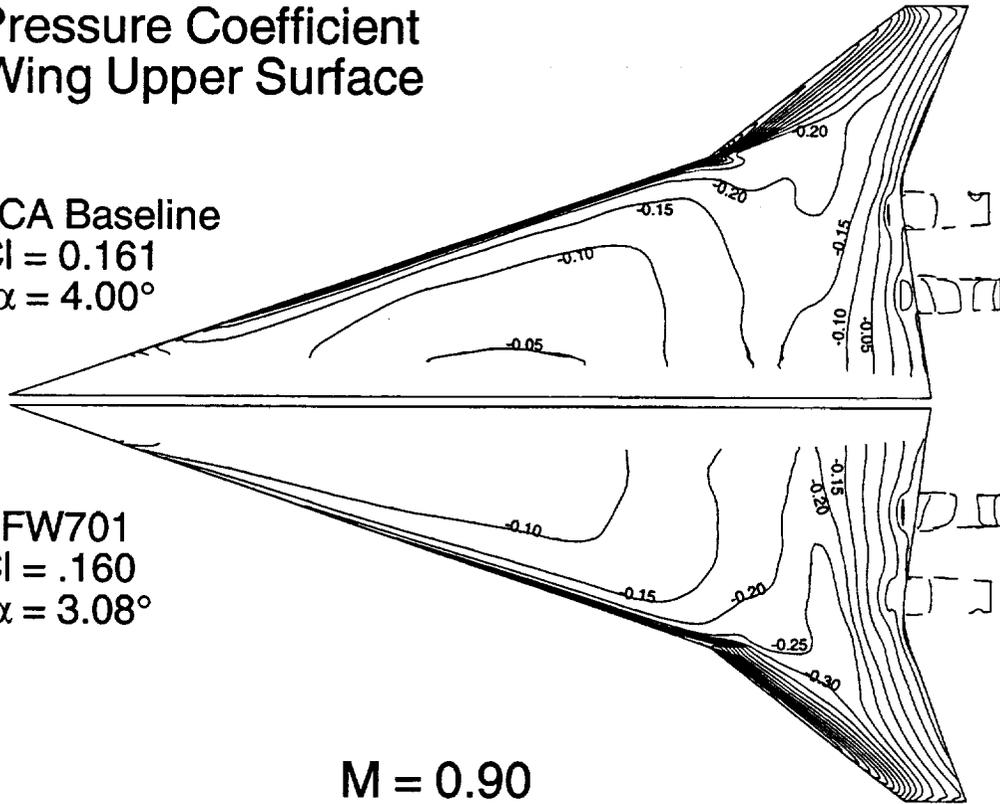
Pressure coefficient distributions on the lower surface of the wings for the TCA baseline and NFW701 configurations at Mach 2.4 are shown in the figure; blank regions near the wing trailing edge are the diverter cut-outs. The pressure coefficient for NFW701 is marginally higher over most of the inboard wing in front of the nacelles; the shock foot prints are somewhat larger as well, but expansions in the shock recovery regions have been reduced. Outboard of the leading edge break, the NFW701 design sees significantly higher pressures.

Pressure Coefficient Wing Upper Surface

TCA Baseline
 $C_l = 0.161$
 $\alpha = 4.00^\circ$

NFW701
 $C_l = .160$
 $\alpha = 3.08^\circ$

$M = 0.90$



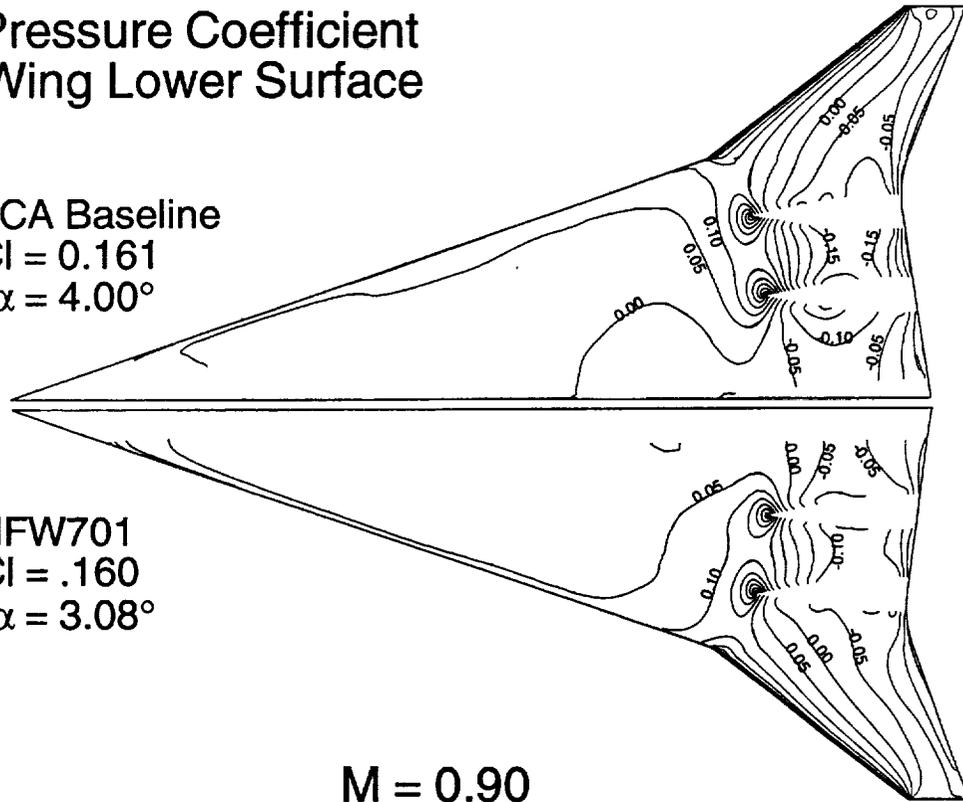
Upper Surface Pressure Coefficient on the TCA Baseline and NFW701 at Mach 0.90

Pressure coefficient distributions on the upper surface of the wings for the TCA baseline and NFW701 configurations at Mach 0.9 are shown in the figure. Both configurations are run at a design C_l of 0.16, but the angle of attack for the baseline and NFW701 configurations are 4.0 and 3.08 degrees, respectively. Once again, the NFW701 design embodies significantly less leading edge suction along the entire span. However, it sees significantly more expansion over the inboard aft section of the wing, with the aft shock further downstream.

Pressure Coefficient Wing Lower Surface

TCA Baseline
 $C_l = 0.161$
 $\alpha = 4.00^\circ$

NFW701
 $C_l = .160$
 $\alpha = 3.08^\circ$



$M = 0.90$

Lower Surface Pressure Coefficient on the TCA Baseline and NFW701 at Mach 0.90

Pressure coefficient distributions on the lower surface of the wings for the TCA baseline and NFW701 configurations at Mach 0.9 are shown in the figure. While the pressure distributions for the two configurations are similar forward of the diverters and outboard of the leading edge break, the NFW701 design sees significantly less expansion aft of the nacelles, particularly between the nacelles.

OVERDISC Design Objectives

- Maintain Leading Edge Bluntness of Initial NFW Design
- Reduce Shock Strength
- Generate Additional Leading Edge Suction Inboard of Inboard Nacelle
- Unload Outboard Wing
- Reduce Upper Surface Trailing Edge Expansion

OVERDISC Design Objectives

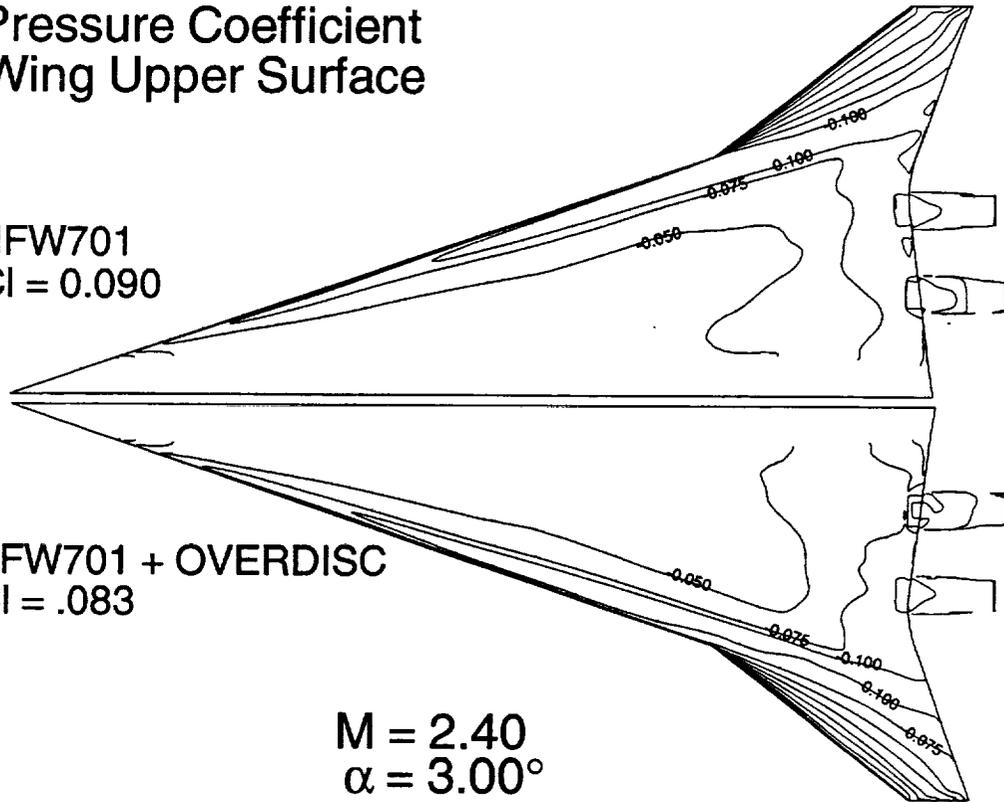
Upon selection of the NFW701 design as the most promising of the configurations developed using the NFW design philosophy, the configuration was redesigned at Mach 2.4 using OVERDISC, and the redesigned configuration was evaluated at Mach 0.90 as well. One of the major constraints applied in the redesign was to maintain the leading edge bluntness of the NFW701 design in an attempt to preserve the transonic performance. Additional flow constraints were applied to reduce the shock strength on the lower surface, generate additional leading edge suction on the upper surface inboard of the inboard nacelle, reduce the loading on the mid and outboard wing sections, and reduce the upper surface expansions near the wing trailing edge.

Pressure Coefficient Wing Upper Surface

NFW701
 $C_l = 0.090$

NFW701 + OVERDISC
 $C_l = .083$

$M = 2.40$
 $\alpha = 3.00^\circ$



Upper Surface Pressure Coefficient on NFW701 and the OVERDISC Redesign at Mach 2.40

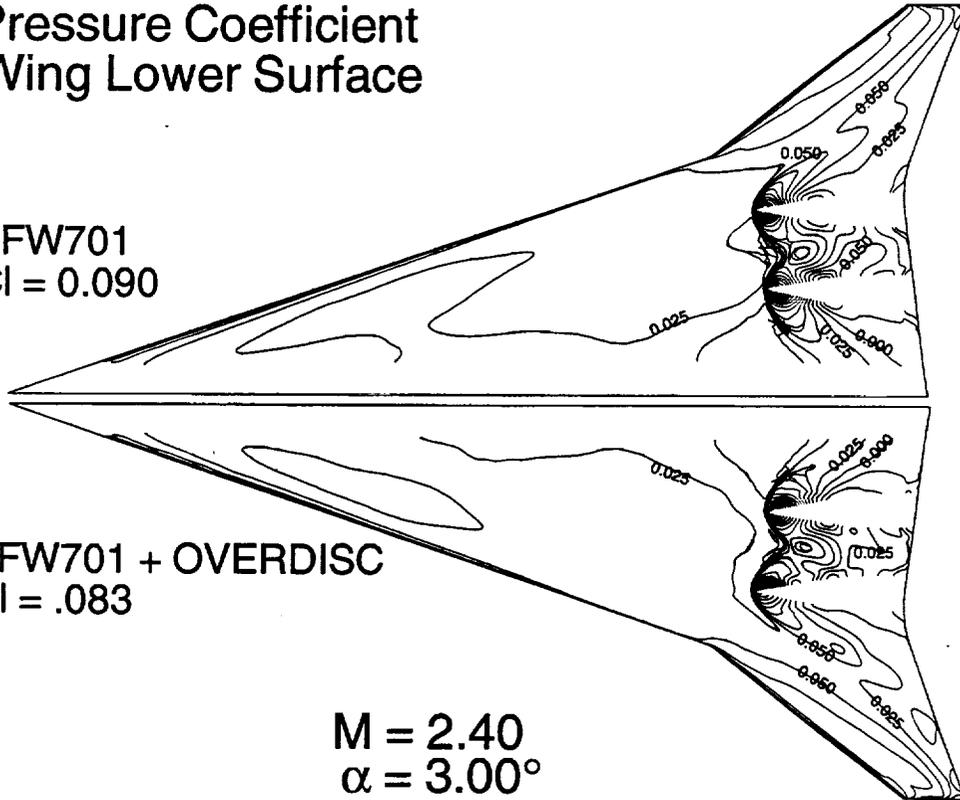
Pressure coefficient distributions on the upper surface of the wings for the NFW701 and OVERDISC redesigned configurations at Mach 2.4 are shown in the figure. Note that both configurations are run at a 3 degree angle of attack, but the lift coefficient for the redesign has dropped down to the specified design C_l . The extension of the leading edge pressure contours upstream of their initial position (see for example the -0.1 contour) indicates that a moderate amount of additional leading edge suction was obtained with the redesign. Similarly, contours at the trailing edge indicate that there is moderately less expansion of the flow in this region.

Pressure Coefficient Wing Lower Surface

NFW701
 $C_l = 0.090$

NFW701 + OVERDISC
 $C_l = .083$

$M = 2.40$
 $\alpha = 3.00^\circ$



Lower Surface Pressure Coefficient on NFW701 and the OVERDISC Redesign at Mach 2.40

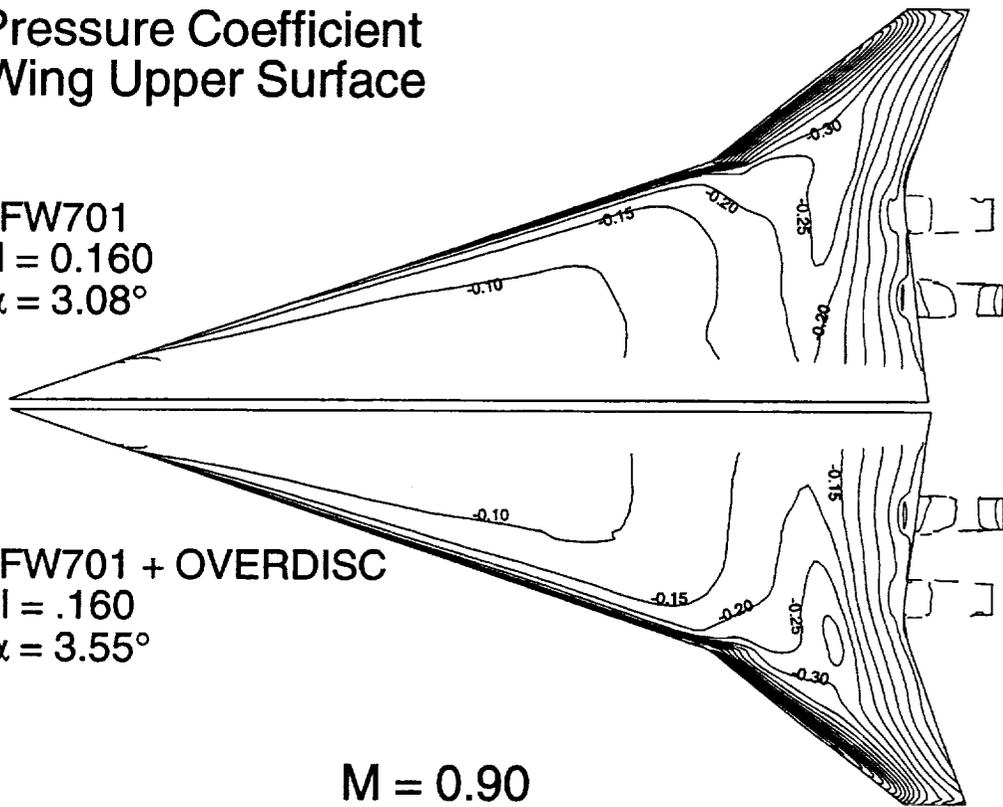
Pressure coefficient distributions on the lower surface of the wings for the NFW701 and OVERDISC redesigned configurations at Mach 2.4 are shown in the figure. While the redesign provided a moderate reduction in the shock strength on the lower wing surface, the reduction was not nearly as large as expected based on the experience in redesigning the BCAG optimized configuration. The reason for this appears to be that significantly more smoothing was utilized in the NFW701 redesign to prevent discontinuities in the surface at the spar locations; that smoothing reduced the degree to which the shock was attenuated.

Pressure Coefficient Wing Upper Surface

NFW701
 $C_l = 0.160$
 $\alpha = 3.08^\circ$

NFW701 + OVERDISC
 $C_l = .160$
 $\alpha = 3.55^\circ$

$M = 0.90$



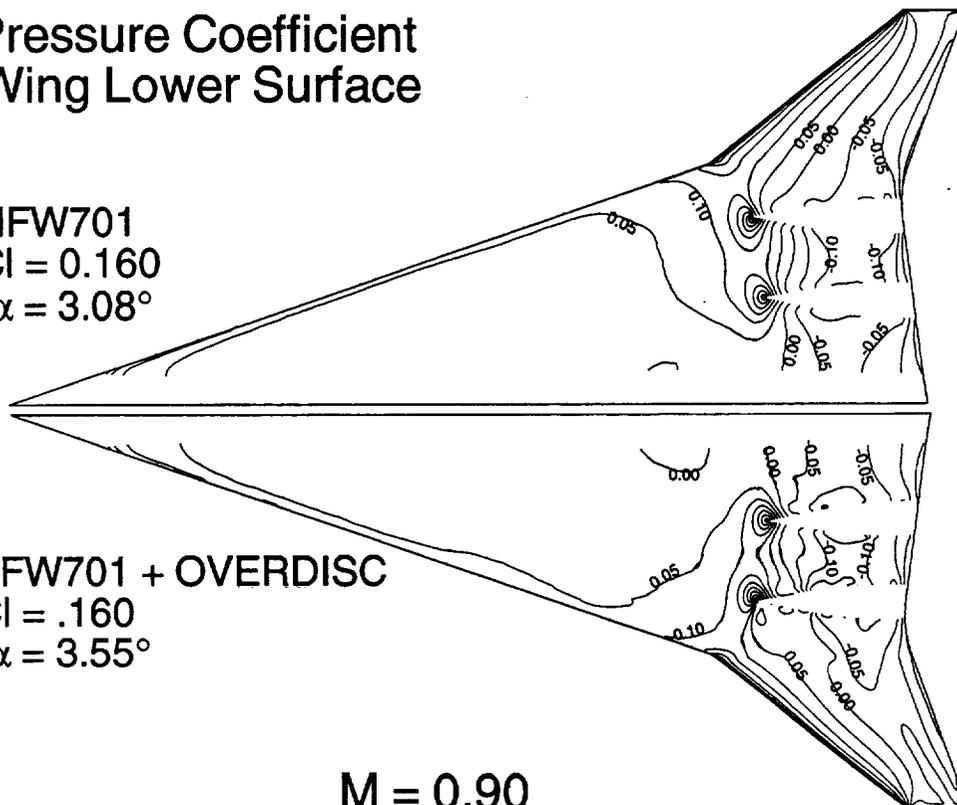
Upper Surface Pressure Coefficient on NFW701 and the OVERDISC Redesign at Mach 0.90

Pressure coefficient distributions on the upper surface of the wings for the NFW701 and OVERDISC redesigned configurations at Mach 0.9 are shown in the figure. Note that both configurations are run at the design C_l of 0.16, but the redesign angle of attack is 3.55 degrees rather than 3.08. There is little to distinguish between the pressure distributions for the two configurations.

Pressure Coefficient Wing Lower Surface

NFW701
 $C_l = 0.160$
 $\alpha = 3.08^\circ$

NFW701 + OVERDISC
 $C_l = .160$
 $\alpha = 3.55^\circ$



$M = 0.90$

Lower Surface Pressure Coefficient on NFW701 and the OVERDISC Redesign at Mach 0.90

Pressure coefficient distributions on the lower surface of the wings for the NFW701 and OVERDISC redesigned configurations at Mach 0.9 are shown in the figure. The most notable difference between the two configurations is on the outboard wing panel, where the redesign has been unloaded to some extent. Note that somewhat larger expansions are beginning to appear between the nacelles with the redesign.

TCA Performance Predictions

$$Re = 4.0 \times 10^6$$

| Configuration | α | CL | CD | Δ CD |
|---------------|----------|--------|---------|-------------|
| $M = 2.40$ | | | | |
| Baseline | 3.00 | 0.8300 | 0.01207 | – |
| NFW701 | 3.00 | 0.8964 | 0.01252 | –0.00014 |
| NFW701 CDISC | 3.00 | 0.8325 | 0.01176 | –0.00034 |
| $M = 0.90$ | | | | |
| Baseline | 4.00 | 0.1608 | 0.01567 | – |
| NFW701 | 3.07 | 0.1599 | 0.01457 | –0.00102 |
| NFW701 CDISC | 3.55 | 0.1601 | 0.01456 | –0.00106 |

TCA Performance Predictions

Performance predictions for the TCA baseline, NFW701, and OVERDISC redesigned NFW701 configurations are shown in the figure. The results indicate that the redesigned configuration provides an additional 2 count drag reduction over that of NFW701 at supersonic cruise while maintaining the same transonic performance improvement over that of the TCA baseline. However, the transonic performance improvement of 10.6 counts does not compare well with flap optimization studies, which indicate that a 26 count drag reduction is obtainable at transonic cruise for the TCA configuration with optimized flaps.

While the NFW design provided significant improvements in transonic performance over that of the TCA baseline, it is apparent that the benefits of the NFW design at transonic cruise cannot be properly evaluated without considering optimal flap settings in the assessment. Moreover, while the viscous analysis of the NFW design indicated a 3.4 drag count reduction over that of the TCA baseline at supersonic cruise, the reduction is significantly less than the roughly 6 drag count reduction obtained in the various optimizations conducted by other participants in the HSR program.

Nevertheless, the NFW design has two unique features which merit further consideration, namely, incorporation of the entire landing gear constraint into the fuselage and the utilization of a blunt rather than sharp leading edge outboard of the wing leading edge break. At the least, the NFW design provides an intriguing alternative starting point (rather than starting from the baseline configuration) for the aerodynamic optimization methods used elsewhere within the HSR program.

Future Plans

- HSR
 - Wind up NFW design of TCA
 - Nacelle/Diverter Redesigns
 - << CDISC redesign of diverter/nacelle
 - << procedures for satisfying inlet flow constraints
 - Powered Effects

- Couple OVERFLOW with an aeroelastics module
 - ELAPS
 - Utilize an OVERDISC type script for regriding

Future Plans

One of the unresolved issues with the NFW designs is determination of the penalty and benefit of utilizing a blunt rather than sharp leading edge outboard of the wing leading edge break at the supersonic and transonic cruise conditions, respectively. This issue will be addressed by modifying the outboard leading edge of the OVERDISC redesigned NFW701 configuration to be sharp and analyzing the resulting configuration at Mach 2.4 and 0.9. While it is believed that additional supersonic performance improvements are obtainable with moderate modifications to the NFW configuration, further redesigns of the wing using OVERDISC are not anticipated at this time. Instead, effort will be spent on redesigning the nacelles and diverters and investigating methods for satisfying constraints on the engine inlet flow.

An additional area of investigation which has been initiated is the analysis of powered effects at transonic cruise. Overset grids for a configuration with the nozzle flaps deflected are currently under construction.

One additional effort which is worthy of note is the coupling of OVERFLOW with an aeroelastics module in order to account for aeroelastic deformations. In this work, OVERFLOW is to be coupled with the ELAPS code using an automated regriding procedure similar to that used with OVERDISC.

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